

TI&E Committee Meeting Attendees November 10, 2015



- Dr. William Ballhaus, Chair
- Mr. Gordon Eichhorst, Aperios Partners
- Mr. Michael Johns, Southern Research Institute (virtual)
- Dr. Matt Mountain, Association of Universities for Research in Astronomy
- Mr. David Neyland, Consultant
- Mr. Jim Oschmann, Ball Aerospace & Technologies Corp.
- Dr. Mary Ellen Weber, STELLAR Strategies, LLC

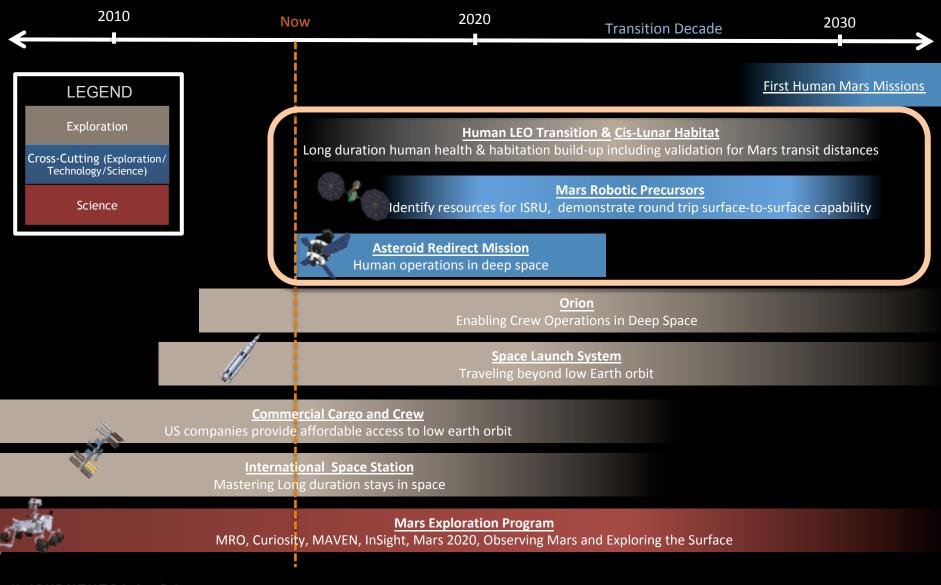
TI&E Committee Meeting Presentations November 10, 2015



- Space Technology Mission Directorate Update
 - Mr. Stephen Jurczyk, Associate Administrator, STMD
- Technology Risk/Challenges Matrix for Humans to Mars and Discussion
 - Mr. Jason Crusan, Director, Advanced Exploration Systems, HEOMD
 - Mr. Jim Reuter, Deputy AA for Programs, STMD
 - Mr. William Gerstenmaier, AA, HEOMD
- Chief Technologist Update
 - Dr. David Miller, NASA Chief Technologist
- Agency Technical Capability Assessment Outcomes
 - Mr. Ralph Roe, NASA Chief Engineer

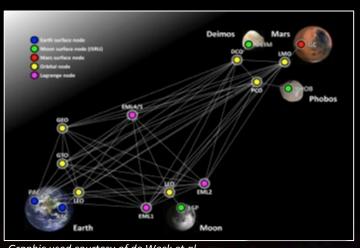
Elements of the Journey to Mars

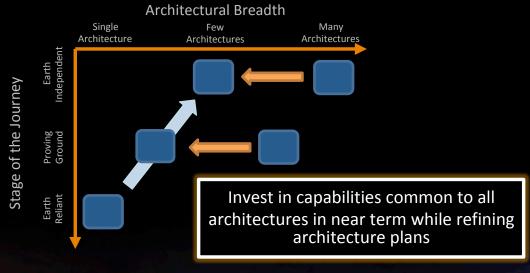




Resilient Architectures for Mars Exploration



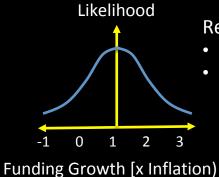




- Graphic used courtesy of de Weck et al
- There are many different architectures and implementation approaches that can be employed on the Journey to Mars
- The first step of each Journey to Mars architecture is the same develop/ validate common required Mars mission capabilities in the 2020s
- The NASA Mission Directorates are collaborating to define a resilient class of architectures for the Journey to Mars in the 2030s
- Concurrently, they will define missions for the 2020s that reduce the risk for this resilient class of architectures

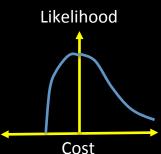
Architectural Value





Resiliency is being robust, or adaptable, to change

- J2M will span decades while changes occur yearly
- Narrow to set of architectures between which exploration can cost-effectively switch as conditions change



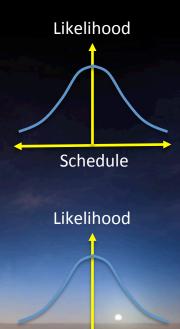
Candidate Architectures



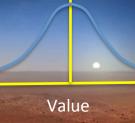
97%

99%

NRC Pathways Evolvable Mars Campaign DRA-5 **Inspiration Mars** Mars One **Mars Society** Modular Mars Architecture Space-X Red Dragon **Explore Mars** Mars Cycler



Proactively planning for change is always better than simply reacting to change as it occurs



95%

Conceptual Integrated Campaign for Mars in the 2020's



LEGEND

Exploration

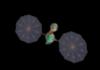
Cross-Cutting (Exploration/ Technology/ Science)

Science

Mars 2020



Mars Orbiter



Round-Trip Surface to Surface



Exploration Precursors



ISRU Prototype

EDL Instruments

Sample Acquisition

> In Situ Science

Habitable Conditions

Ancient Life Resource Survey

Landing Site Selection

Optical Comm/Relay

High Power SEP

Rendezvous

Remote Sensing Instruments **Dust Toxicity**

EDL Evolution/ Instruments

Mars Ascent

Surface Navigation

Returned Sample Analysis ISRU Production

Surface Power for ISRU

Rad/ECLSS Validation

Increased EDL Mass & Precision

Science Instruments

2020

2022

Future Launch Opportunities

Integrated Vision for a Mars Robotic Precursor Initiative



Exploration:

- Address key issues to build confidence in round-trip missions to/from Mars
- Identify and characterize concentrated resources for potential ISRU exploitation

Science:

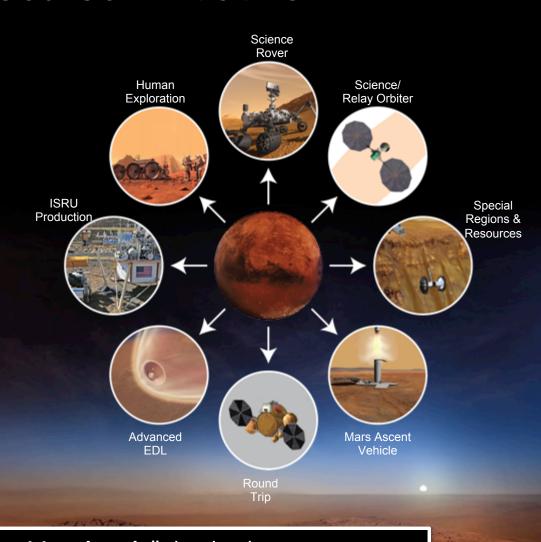
- Leverage expertise built through five decades of robotic Mars exploration
- Build upon recent science discoveries
- Continue to support decadal priorities

Technology:

- Leverage technology investments
- Mission Infusion opportunities
- Enable end-to-end Earth/Mars missions

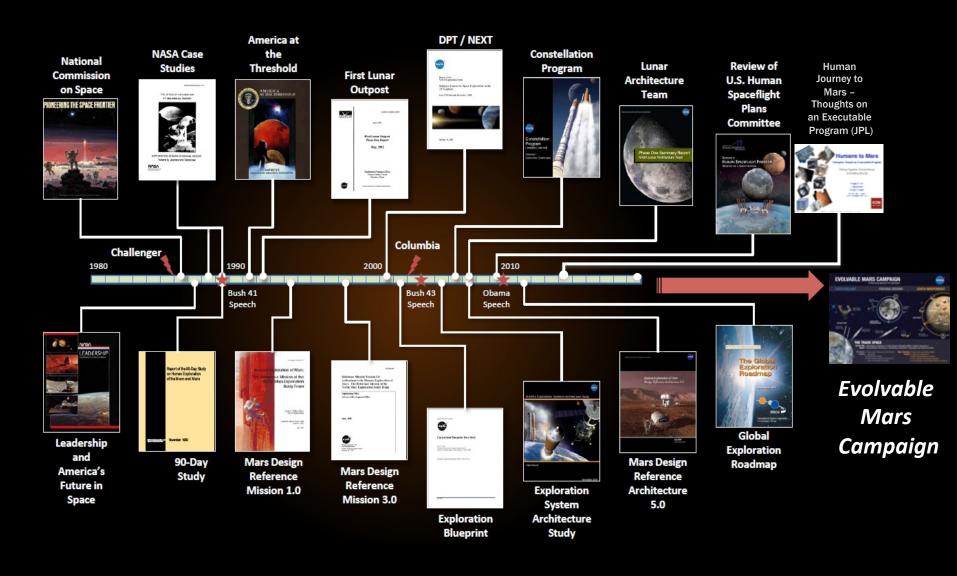
Infrastructure:

 Sustain and improve Mars telecommunications and surface reconnaissance infrastructure

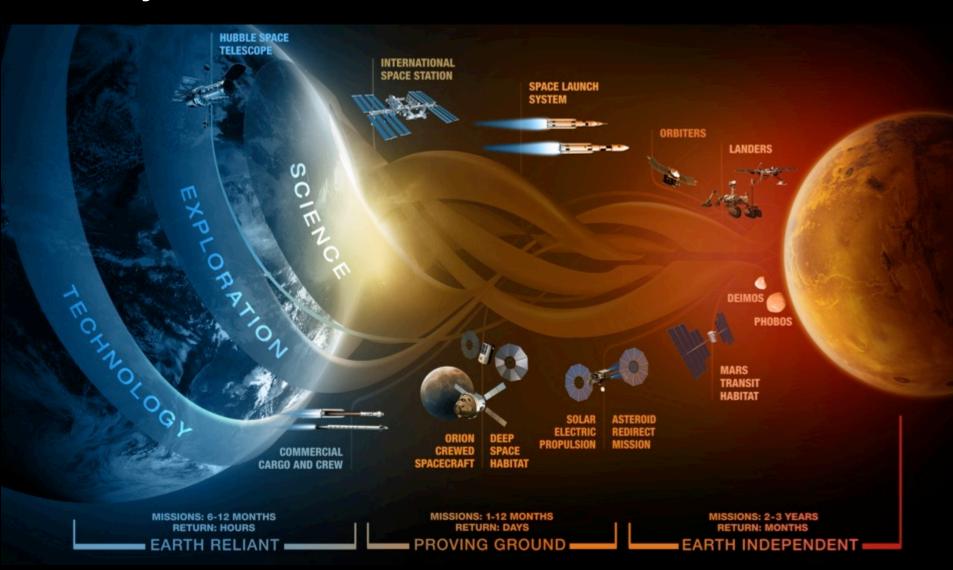


The 2020's will be a "transition decade" that leads to Humans to Mars in the 2030's

A Brief History of Beyond-LEO Spaceflight Architecture Development



Journey to Mars



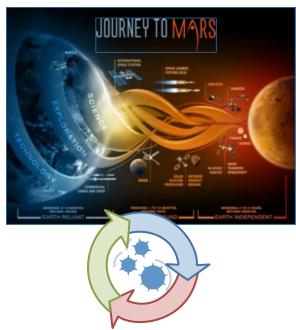
Design Reference Missions vs Design Philosophy







- Internal NASA and other Government
- International Partners
- Commercial and Industrial
- Academic
- Technology developments
- Science discoveries



Evolvable Mars Campaign

- An ongoing series of architectural trade analyses that we are currently executing to define the capabilities and elements needed for a sustainable human presence on Mars
- Builds off of previous studies and ongoing assessments
- Provides clear linkage of current investments (SLS, Orion, etc.) to future capability needs

STMD Strategic Planning



· Core values, guiding principles, implementation goals flowdown



· Get There, Land There, Live There, Observe There, Invest Here





 Stakeholder input: Space Technology Roadmaps, NRC recommendations, STIP, MD roadmaps, Roundtables, etc.



Thrust Areas

 Focused areas of STMD investments

STMD Strategic Themes

Get There

Improve the ability to efficiently access and travel through space

Land There

Enable the capability of landing more mass, more accurately, in more locations throughout the solar system

Live There

Make it possible to live and work in deep space and on planetary bodies

Observe There

Transform the ability to observe the universe and answer the profound questions in Earth and space sciences

Invest Here

Enhance the nation's aerospace capabilities and ensure its continued technological leadership

National Science and Technology Priorities





Content Generation



Technology Portfolio

Principal Technologists:

Technology investment plans

 Crosscutting Investment strategy and content selection



STMD Programs Implementation instruments

HEOMD/STMD Engagement on Technology Needs



- Evolvable Mars Campaign (EMC) has a strategic set of needs for enabling long-range capabilities; Orion and SLS needs are primarily near-term and mission focused.
- Crosscutting needs identified by HEOMD:
 - Radiation monitoring & protection (ISS, Orion, HRP, EMC)
 - EVA suit & PLSS (Orion, ISS, ARM, EMC)
 - Environmental monitoring (Orion, ISS, EMC)
 - Spacecraft fire safety (Orion, ISS, EMC)
 - Exercise equipment (Orion, HRP, EMC)
 - Advanced solar arrays (ARM, ISS, EMC)
 - Automated rendezvous & docking (Orion, ARM, EMC)
- Areas with greatest number of gaps:
 - Human Health, Life Support, & Habitation Systems (Orion, HRP)
 - Communications & Navigation (SCAN)
- Categories of collaboration:
 - Deliveries: STMD matures technology and delivers to AES for system-level evaluation (e.g., RCA, VOR, EVA Gloves, RPM instruments, etc.)
 - **Partnerships:** STMD and HEOMD/AES co-fund the development of technologies that are of mutual interest (e.g., MOXIE, MEDA, MEDLI-2, SCOR, etc.)
 - Coordination: STMD and HEOMD/AES define specific divisions of responsibility within a technical discipline (e.g., nuclear systems, synthetic biology, advanced manufacturing, etc.)

Capabilities for Pioneering Space: Steps on the Journey to Mars



	Mission Capability	ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Cis-Mars Robotic	Mars Orbit	Mars Surface
ce and	In Situ Resource Utilization & Surface Power		Exploratory ISRU Regolith	Exploratory ISRU	Exploratory ISRU & Atmosphere	Exploratory ISRU	Operational ISRU & High Power
ng in Spa On Mars	Habitation & Mobility	Long Duration with Resupply	Initial Short Duration	Initial Long Duration		Resource Site Survey	Long Duration / Range
Working in Space and On Mars	Human/Robotic & Autonomous Ops	System Testing	Crew-tended	Earth Supervised	Earth Monitored	Autonomous Rendezvous & Dock	Earth Monitored
M	Exploration EVA	System Testing	Limited Duration	Full Duration	Full Duration	Full Duration	Frequent EVA
	Crew Health	Long Duration	Short Duration	Long Duration	Dust Toxicity	Long Duration	Long Duration
Staying Healthy	Environmental Control & Life Support	Long Duration	Short Duration	Long Duration	Long Duration	Long Duration	Long Duration
	Radiation Safety	Increased Understanding	Forecasting	Forecasting Shelter	Forecasting Shelter	Forecasting Shelter	Forecasting & Surface Enhanced
	Ascent from Planetary Surfaces				Sub-Scale MAV	Sub-Scale MAV	Human Scale MAV
tion	Entry, Descent & Landing				Sub-Scale/Aero Capture	Sub-Scale/Aero Capture	Human Scale EDL
orta	In-space Power & Prop		Low power	Low Power	Medium Power	Medium Power	High Power
Transportation	Beyond LEO: SLS & Orion		Initial Capability	Initial Capability	Full Capability	Full Capability	Full Capability
	Commercial Cargo & Crew	Cargo/Crew	Opportunity	Opportunity	Opportunity	Opportunity	Opportunity
	Communication & Navigation	RF	RF & Initial Optical	Optical	Deep Space Optical	Deep Space Optical	Deep Space Optical
EARTH PROVING GROUND INI				EARTH INDEPENDENT			



Deep Space Optical

EARTH INDEPENDENT

Deep Space Optical

Deep Space Optical

Optical

PROVING GROUND

	Capabilities for Pioneering Space: Steps on the Journey to Mars STMD Focus Areas						NASA
	Mission Capability	ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Cis-Mars Robotic	Mars Orbit	Mars Surface
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Tra	Commercial Cargo & Crew	Cargo/Crew	Opportunity	Opportunity	Opportunity	Opportunity	Opportunity

RF & Initial Optical

RF

EARTH

RELIANT

Working in Space On Mars	+ + +
Staying Healthy	E

Stayin Health	Environmental Cor Life Support				
	Radiation Safety				
	Ascent from Plane				

Communication &

STMD focus areas

Navigation

In Situ Resource Utilization & Surface Power

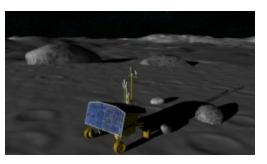


Objectives

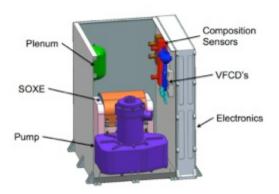
- Reduce logistical support from Earth by utilizing local resources to produce water, oxygen, propellants, and other consumables.
- Generate abundant power for surface systems.

Current Activities

- Resource Prospector: Formulating robotic mission to prospect for ice and other volatiles in polar regions of the Moon. (AES)
- Mars Oxygen ISRU Experiment (MOXIE):
 Demonstration of oxygen production from the Mars atmosphere on the Mars 2020 mission. (AES/STMD)
- Fission Surface Power: Ground demonstration of Stirling power conversion technology and small nuclear reactors for 1-10 kW modular surface power systems. (STMD)



Resource Prospector



MOXIE



Kilopower fission surface power system

Entry, Descent, and Landing (EDL)



Objectives

 Develop the capability to land heavy payloads (> 18 mt) on Mars for human missions.

Current Activities

- Low Density Supersonic Decelerator (LDSD): Flight test of supersonic aerodynamic decelerator and supersonic ring sail parachute for future robotic missions to Mars. (STMD)
- Hypersonic Inflatable Aerodynamic Decelerator (HIAD):
 Conducted sounding rocket flight tests of subscale HIAD. (STMD)
- Adaptable Deployable Entry & Placement Technology (ADEPT):
 Deployable, semi-rigid aeroshell. (STMD)
- Supersonic Retro Propulsion: Learning from SpaceX flyback booster tests. (STMD)
- Advanced Thermal Protection System (TPS) materials:
 Developing woven and high heat flux TPS materials. (STMD)
- Entry Systems Modeling: Updating and improving computational fluid dynamics codes to reduce design uncertainties for future missions. (STMD)
- Autonomous Landing & Hazard Avoidance Technology
 (ALHAT): Flight test of ALHAT system on Morpheus lander. (AES)
- Mars Entry, Descent, & Landing Instrumentation (MEDLI-2):
 Measuring temperatures and pressures on Mars 2020 heat shield to validate aerothermal models. (AES/STMD)
- EDL Pathfinder: Studying EDL Pathfinder mission to Mars in 2026 to test subscale EDL system for human missions. (EMC)



LDSD flight hardware



HIAD engineering model



ALHAT testing on Morpheus lander

Environmental Control & Life Support



Objectives

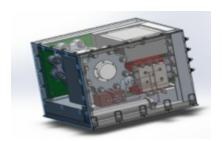
- Develop highly-reliable life support systems that recycle air, water, and waste to reduce consumables.
- Demonstrate next generation life support systems with integrated groundbased testing and ISS flight experiments.

Current Activities

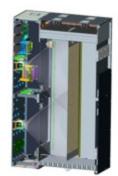
- Spacecraft Oxygen Recovery: Developing technologies to recover at least 75% of the oxygen from a spacecraft atmosphere revitalization system. (STMD)
- Sorbents for CO₂ Removal: Developing new sorbents that do not generate dust. (AES)
- High Pressure Oxygen Generation: Providing oxygen supply for replenishing space suits. (AES)
- Waste Water Processing: Developing green pre-treatments, Cascade Distillation System, and Biological Water Processor. (AES/STMD)
- Spacecraft Atmosphere Monitor: Instrument for detecting trace gas contaminants in ISS air. (AES)
- PCM Heat Exchanger: Developing a large-scale Phase Change Material heat exchanger to maintain the crew cabin within safe/comfortable temperatures throughout exploration missions. (STMD)
- Spacecraft Fire Safety: Saffire experiments will investigate the spread of fires in microgravity. Also developing technologies for fire suppression, combustion products monitoring, and post fire clean-up. (AES)
- Next Space Technology Exploration Partnerships (NextSTEP):
 Developing advanced CO₂ removal technologies, modular ECLSS, and hybrid biological and chemical life support systems. (AES)



Cascade Distillation System



Spacecraft Atmosphere
Monitor



Saffire Fire Safety Experiment

= Sufficiently Funded

Sub-Scale MAV

Sub-Scale/Aero

Capture

Medium Power

Full

Capability

Opportunity

Deep Space

Optical

Opportunity

Optical

PROVING GROUND

Sub-Scale MAV

Sub-Scale/Aero

Capture

Medium Power

Full

Capability

Opportunity

Deep Space

Optical



Human Scale

MAV

Human Scale EDL

High Power

Full

Capability

Opportunity

Deep Space

Optical

EARTH INDEPENDENT

Capability Development Risk Reduction				= Partially Funded = Not Funded		NASA	
	Mission Capability	ISS	Cis-lunar Short Stay (e.g. ARM)	Cis-lunar Long Stay	Cis-Mars Robotic	Mars Orbit	Mars Surface
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Transportation

Commercial Cargo & Crew

Communication &

Navigation

Radiation Safety Forecasting **Understanding Shelter Ascent from Planetary Surfaces** Entry, Descent & Landing In-space Power & Prop Low power **Low Power** Initial Beyond LEO: SLS & Orion **Initial Capability** Capability

Cargo/Crew

RF

EARTH

RELIANT

Opportunity

RF & Initial Optical

Current Capability Risks



Capabilities	LXC	Rationale
In Situ Resource Utilization & Surface Power		Resource Prospector and MOXIE are small-scale demonstrations of ISRU on planetary bodies. These would need to be significantly scaled up to support human exploration needs.
Habitation & Mobility		ISS is demonstrating long-duration habitation in LEO, but duration depends on resupply. Conceptual studies are underway for short duration cis-lunar habitats.
Human/Robotic & Autonomous Ops	~	Human/Robotic & Autonomous Ops are being demonstrated on ISS. Substantial additional work is needed to enable maintenance of human exploration systems.
Exploration EVA	orl'	Uncertain if next generation spacesuit will be ready before 2024 for demonstration on ISS.
Crew Health	in Work	Human Research Program is investigating crew health risks on ISS, and developing medical diagnostics and countermeasures. Some health risks may not be controlled by 2024.
Environmental Control & Life Support	ent	ISS life support systems require frequent maintenance. New ECLSS technologies are being demonstrated on ISS. Long duration, closed-loop, system-level ECLSS demonstration is being planned.
Radiation Safety	Risk Assessment	Characterizing LEO, cis-lunar, and Mars surface radiation environments. Improving forecast models for solar particle events. Reducing uncertainly in radiation effects on humans. Effective shielding has not been developed.
Ascent from Planetary Surfaces	Ass	Little work is being done in this area except for MAV concept studies and small LOX-methane propulsion efforts.
Entry, Descent & Landing	Risk	There are multiple EDL technology development activities for Mars robotic missions but analogous projects for human missions are in early stages of progress.
In-space Power & Propulsion		Developing 40 kW SEP system for ARM. Initiating ground testing of 100 kW electric thrusters. Developing small fission reactors for surface power (low funding level).
Beyond LEO: SLS & Orion		Working towards first flight of SLS and Orion in 2018.
Commercial Cargo & Crew		Working towards Commercial Crew IOC in 2018. Opportunities for resupply of cislunar habitats.
Communication & Navigation		Demonstrating high bandwidth optical communications for cis-lunar and Mars. Deep space optical comm is a candidate for demonstration on SMD missions.



By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow.

-President Barack Obama, April 15, 2010

NASA'S JOURNEY TO MARS

TI&E Committee Observation



HEOMD and STMD working together have identified a range of critical technologies and further capabilities required to support human missions to Mars.

- NASA has a broad range of architectural landscape options and is working to narrow them.
- NASA is defining a common set of technology investment requirements across these architectures.
- They have identified gaps in the areas of: power & in-space propulsion, ECLSS, habitation, ISRU, communications & navigation.

TI&E Committee Finding



In order to assess the technology investment matrix, the TI&E committee would need the following:

- A mission definition
- A plan that includes technology risk burn down lead times and tech demo completion dates
- Budget commitments and authority to proceed dates
- An assessment of technologies that could be effectively evaluated on extant ISS environment

In the absence of these items, the committee offers the following:

- The committee has been told that NASA budget limitations and uncertainties are a significant impediment to a human exploration mission to Mars in the 2030s with SLS, Orion, and other system developments as the current near term pacing items in human exploration.
- NASA has defined what budget it needs in STMD, but the discretionary portion has diminished over time, and has forced many of the planned technology investments and demo risk reduction missions to be significantly delayed, descoped, or eliminated.

TI&E Committee Finding (continued)



To effectively advocate to correct this situation, in the absence of a defined mission plan to go to Mars, this committee believes the preferred approach is to develop the technology pull from the proving ground missions

- The committee believes the current HEOMD efforts must demonstrate measurable progress in most of the essential areas enabling future HE missions
- At a cadence that maintains US human space leadership and US public support
- Must address major technology gaps (power & in-space propulsion, ECLSS, habitation, ISRU, communications & navigation) with timeline for need dates and appropriate investment

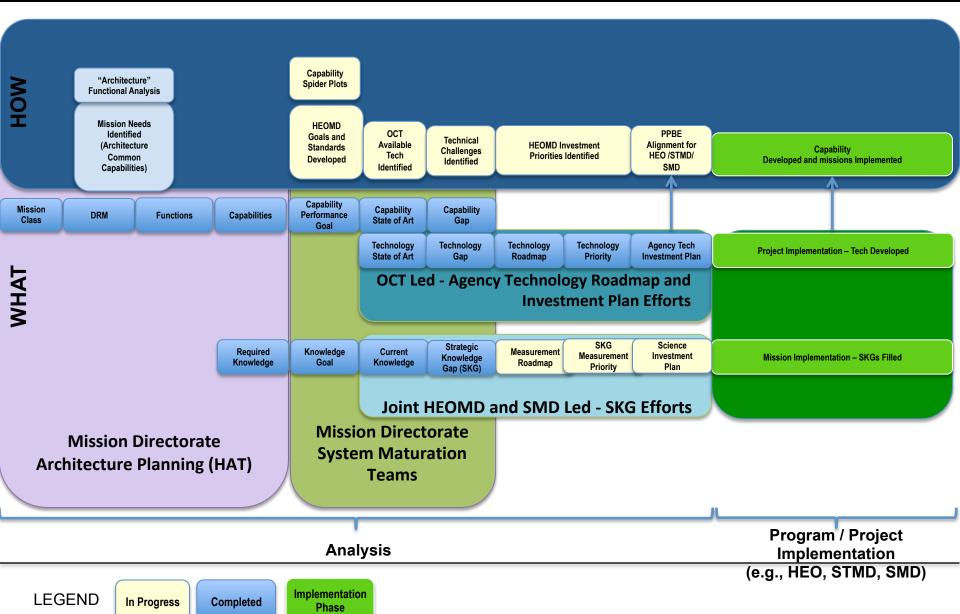


BACK-UP



NASA Technology Roadmaps & Investment Plan







Current Technical Capability Area Leadership

Discipline-level Technical Capability — OCE Leadership with NASA Technical Fellows

- 1. Aerosciences
- 2. Avionics
- 3. Electrical Power
- 4. Flight Mechanics
- 5. GN&C
- 6. Human Factors
- 7. Life Support/Active Thermal
- 8. Loads and Dynamics
- 9. Materials
- 10. Mechanical Systems

- 11. NDE
- 12. Passive Thermal
- 13. Propulsion
- 14. Software
- 15. Structures
- 16. Systems Engineering (new)
- 17. Space Environments (new)
- 18. Cryogenics (new)
- 19. Instruments and Sensors (new)

Note: (new) signifies that a Capability assessment has not been conducted or reviewed by the EMB

System-level Technical Capability — OCE Interim Leadership

- 1. Entry, Descent, and Landing
- 2. In-Situ Resource Utilization
- 3. Rendezvous and Capture
- 4. Autonomous Systems (new)